SIGNALS OF SUPERSYMMETRIC DARK MATTER

AFSAR ABBAS

Institute of Physics, Bhubaneswar-751005, India
(e-mail : afsar@iopb.res.in)

Abstract

The Lightest Supersymmetric Particle predicted in most of the supersymmetric scenarios is an ideal candidate for the dark matter of cosmology. Their detection is of extreme significance today. Recently there have been intriguing signals of a 59 Gev neutralino dark matter at DAMA in Gran Sasso. We look at other possible signatures of dark matter in astrophysical and geological frameworks. The passage of the earth through dense clumps of dark matter would produce large quantities of heat in the interior of this planet through the capture and subsequent annihilation of dark matter particles. This heat would lead to large-scale volcanism which could in turn have caused mass extinctions. The periodicity of such volcanic outbursts agrees with the frequency of palaeontological mass extinctions as well as the observed periodicity in the occurrence of the largest flood basalt provinces on the globe. Binary character of these extinctions is another unique aspect of this signature of dark matter. In addition dark matter annihilations appear to be a new source of heat in the planetary systems.

Careful measurements on the dynamics of galaxies by Fritz Zwicky back in the 1930's led him to the conclusion that the mass to light ratio of galaxies and clusters of galaxies required far more mass than explained on the basis of stellar origin of their light. Hence he argued for the existence of invisible dark matter. His ideas were not immediately appreciated and it took several decades for astronomers and physicists to understand the significance of this discovery. Today, on the basis of several experimental observations, it has become clear that to account for the observed motion in the cosmos, gravitational fields much stronger than those attributable to luminous matter are required. As much as 90% of the mass in the universe is constituted of this invisible dark matter.

This conclusion gets further support from simulations using cosmological models which bring out the necessity for large number of relic particles from the early universe. The ideal candidate for these relic species are the weakly interacting massive particles (WIMPS). These WIMPS arise most naturally in Supersymmetric theories.

Most of the supersymmetric theories contain one stable particle , the so called Lightest Supersymmetric Particle (LSP), which is the candidate for dark matter as a WIMP. The existence of a stable supersymmetric partner particle results from the fact that these models include a conserved multiplicative quantum number, the R-parity. This takes on values of +1 and -1 for particle and supersymmetric partners respectively. As per this conservation principle SUSY particles can only be generated in pairs.This requires that SUSY particles may decay in odd number of particles only. As such the LSP must be stable.

However the R-parity may be violated. The quantum number R is given by

$$R = (-1)^{3B+L+2S} \tag{1}$$

where B is baryon number, L is lepton number and S is the spin. A violation of B or L implies a violation of R number. However sharp bounds on the violation of R have been established.

Had LSP been susceptible to the strong or the electromagnetic interactions, then it would have been detectable today, as it would have condensed with ordinary matter. Bounds on the abundance of LSP normalized with respect to the abundance of proton have been calculated [1]

$$\frac{n(LSP)}{n(p)} \sim 10^{-10}(strong) \ldots 10^{-6}(electomagnetic) \tag{2}$$

Hence LSP should be practically bereft of the strong or the electromagnetic interactions. It can however take part in gravitational and weak interactions. So these are ideal candidates for the WIMP scenarios of the cosmological dark matter. SUSY dark matter particles are of interest as they occur in a totally different context and not specifically introduced to solve the dark matter problem.

Possible candidates for the LSP include the photino (S=1/2), the higgsino (S=1/2), the zino (S=1/2), the sneutrino (S=0) and the gravitino (S=3/2). The above spin 1/2 SUSY particles are called gauginos. In most of the recent theories the favourite LSP is the neutralino which is defined as the lowest mass linear superposition of photino ($\tilde{\gamma}$), zino ($\tilde{Z}$) and the two higgsino states ($\tilde{H}_1$, $\tilde{H}_2$) :

$$\chi = a_1\tilde{\gamma} + a_2\tilde{Z} + a_3\tilde{H}_1 + a_4\tilde{H}_2 \tag{3}$$

Within the Minimal Supersymmetric extension of the Standard Model (MSSM) , it is convenient to describe the supersymmetry phenomenology at the electroweak scale without too strong theoretical assumptions. Various properties like relic abundances and detection rates have been carefully analyzed recently by several authors [2]. In the soft-breaking Lagrangian one has the trilinear and bilinear breaking parameters.

Either looking for signatures of the dark matter or detecting it directly is obviously, a major enterprise today [1]. To understand the properties of the elusive and invisible dark matter, one may try to detect the dark matter directly or look for situations where it would have left its indelible fingerprints. The latter would be referred to as indirect detection.

First the direct detection. The most exciting news is that recently there have been intriguing tell-tale signs of dark matter. There are several detectors all over the world trying to catch a dark matter particle, Most of them focus on WIMP-nucleus elastic scattering from target nuclei part of the detector. The putative WIMP would be detected via nuclear recoil energies which are expected to be in the kilo-electronvolt range.

The experiment, which has found possible signature of dark matter, is DAMA, which is housed deep underground in the INFN Gran Sasso National Laboratory in Italy [3]. It this detector high atomic-number target nuclei, such as Iodine (in the form of NaI) and Xenon are used. To help isolate a possible WIMP signal from the background, one focuses on the annual modulation effect. As the earth rotates around the sun, the dynamics are such that its rotational velocity would be in the same direction as that of the solar system with respect to the galaxy in June and opposite in December. This would bring in an annual modulation in the WIMP detection rate. The 100 kg DAMA detector, after two years of data collection on this modulation effect, has enabled the experimental group to announce the possible detection of a 59 Gev WIMP, most likely a neutralino [3]. This is a most significant discovery in the direct dark matter detection set-ups. Further work continues to be done to consolidate or refute this discovery.

One may ask for possible indirect signatures of the dark matter in the universe. One has to seek out special and unique scenarios in the astrophysical or geological context to obtain unique signatures of dark matter. A few such scenarios studied by us are described below [4,5].

While investigating the possibility that a WIMP could explain both the dark matter problem and the solar neutrino problem, Press and Spergel [6] estimated the rate at which the sun or a planet will capture WIMPs. As given by Krauss et al the capture rate for earth is [7] :

$$\dot{N_E} = (4.7 \times 10^{17} sec^{-1})\{3ab\} \left[\frac{\rho_{0.3}\sigma_{N,32}}{\bar{v}_{300}^3}\right] (\frac{1}{1 + m_X^2/m_N^2}) \tag{4}$$

where m_X is the mass of the DM particle, m_N is the mass of a typical nucleus off which the the particle elastically scatters with cross-section σ_N, ρ_X is the mean mass density of DM particles in the Solar System, $\bar{v}$ is the r.m.s. velocity of dark matter in the Solar System, $\rho_{0.3} = \rho_X/0.3GeVcm^{-3}$, $\sigma_{N,32} = \sigma_N/10^{-32}cm^2$, $\bar{v}_{300} = \bar{v}/300kms^{-1}$, and a and b are numerical factors of order unity which depend on the density profile of the sun or planet.

The earth will continue to accrete more and more particles until their number density inside the planet becomes so high that they start to annihilate. One possibility is a flux of upwardly moving neutrinos at the earth's surface. This has been studied very meticulously and is being used to detect dark matter directly [7-9]. We ignore this channel and study other possible outcomes of the said annihilation of dark matter at the centre of earth. This had not been studied earlier.

Depending on whether the dark matter is neutralino, photino, gravitino, sneutrino, Majorana neutrino or some other, different annihilation channels are possible [8-10]. Note that we are however, looking in particular, at neutralino in the supersymmetry broken scenario of the MSSM as described above [2]. Generally the most significant channels are $\chi\bar{\chi} \rightarrow q\bar{q}$ (quark-antiquark), $\chi\bar{\chi} \rightarrow \gamma\gamma$ (photons) and $\chi\bar{\chi} \rightarrow l\bar{l}$ (lepton-antilepton).

We ignore the $\nu\bar{\nu}$ which has been well studied by others [8-10] and concentrate upon photon producing channels. In the quark channel hadronization will take place through jets and subsequent radiative decay will lead to mesons which in turn will decay through their available channels. Hence [10] :

$$\chi\bar{\chi} \rightarrow q\bar{q} \rightarrow (\pi^0, \eta, ...) \rightarrow \gamma + Y \tag{5}$$

All annihilation processes which directly or indirectly create photons, energy is delivered to the core through inelastic collisions. This would lead to the generation of heat in the earth's core. We wish to study this heat generation in the core through annihilation. This heat is :

$$\dot{Q}_E = e\dot{N}_E m_X \tag{6}$$

where e is the fraction of annihilations which lead to the generation of heat in the core of the earth. Here e may be as large as unity for the ideal case where the WIMPs annihilate predominantly through photons only. For an order of magnitude estimate let us take it to be ~ 0.5 [8-10].

On taking $ab \sim 0.34$ [2], $\rho_{0.3} = 1$, $\bar{v}_{300} = 1$, $m_X = 55GeV$ and the cross-section on iron to be $\sigma_N = 10^{-33}cm^2$, one finds that $\sim 10^8W$ of heat is generated.

As the visible matter clumps together to form stars, planets, etc. an interesting question is whether the dark matter also displays this tendency of clumping. Interestingly several dark matter models do suggest that clumps of dark matter arise naturally during the course of evolution of the universe. Silk and Stebbins [11] considered cold dark matter models with cosmic strings and textures appropriate for galaxy formation. They found that a fraction 10^{-3} of the galactic halo dark matter may exist in the form of dense cores. These may survive up to mass scales of $10^8 M_\odot$ in galaxy halos and globular clusters [11]. Analyzing the stability of these clumps of dark matter, they found that the cores of these clumps will not be affected, although the outer layers may be stripped off by tidal forces. In the cosmic string model, the clumpiness C, defined as the ratio of clumped matter concentration to normal concentration, of dark matter at the present epoch would be [11]

$$C \sim 10^{12} f_{cl} h^6 \Omega_0^3 \tag{7}$$

where f_{cl} is the fraction of dark matter in clumps, H is the Hubble parameter parametrized as 100 $h\ km/s\ Mpc^{-1}$, and Ω_0 is the closure energy density of the Universe.

Subsequently Kolb and Thachev [12] studied isothermal fluctuations in the dark matter density during the early universe. If the density of the isothermal dark matter fluctuation or clumps, $\Phi = \delta\rho_{DM}/\rho_{DM}$, exceeds unity, a fluctuation collapses in the radiation-dominated epoch and produces a dense dark matter object. They found the final density of the virialized object ρ_F to be

$$\rho_F \sim 140\Phi^3(\Phi + 1)\rho_x \tag{8}$$

where ρ_x is equilibrium density.

For axions, a putative dark matter particle, density fluctuations can be very high, possibly spanning the range $1 < \Phi < 10^4$. The resultant density in miniclusters can be as much as 10^{10} times larger than the local galactic halo density. The probability at present of an encounter of the earth with such an axion minicluster is 1 per 10^7 years with $\Phi = 1$. Kolb and Tkachev found two types of axion clumps arising from two kinds of initial perturbations:

- Fluctuations with $10^{-3} < \Phi < 1$ collapse in the matter-dominated epoch.
- Fluctuations with $\Phi > 1$ collapse in the radiation-dominated epoch.

If the dark halo is mostly made of neutralinos, then the clumping factor in the MSSM could be less than 10^9 for all neutralino masses [13].

It has been estimated that these clumps would cross earth with a periodicity of 30-100 Myrs [14]. Thus during the passage of the earth through such clumps at regular intervals, the flux of the incident DM particles will increase by roughly a factor of $\sim 10^9$. Consequently the value of $\dot{Q}_E$ during the passage of a clump will be $\sim 10^{17}$ W [4].

Improving upon the previous work, Gould [15] obtained greatly enhanced capture rates for the earth (10-300 times that previously believed) when the WIMP mass roughly equals the nuclear mass of an element present in the earth in large quantities, thereby constituting a resonant enhancement. Gould's formula gives the capture rate for each element in the earth as [15] :

$$\dot{N_E} = (4.0 \times 10^{16} sec^{-1}) \bar{\rho}_{0.4} \frac{\mu}{\mu_+^2} Q^2 f \left\langle \hat{\phi}(1 - \frac{1 - e^{-A^2}}{A^2}) \xi_1(A) \right\rangle \tag{9}$$

where $\bar{\rho}_{0.4}$ is the halo WIMP density normalized to $0.4 GeV cm^{-3}$, $Q = N - (1 - 4 sin^2 \theta_W) Z \sim$ N - 0.124Z, f is the fraction of the earth's mass due to this element, $A^2 = (3v^2\mu)/(2\hat{v}^2\mu_-)$, $\mu = m_X/m_N$, $\mu_+ = (\mu + 1)/2$, $\mu_- = (\mu - 1)/2$, $\xi_1(A)$ is a correction factor, $v =$ escape velocity at the shell of earth material , $\hat{v} = 3kT_w/m_X = 300 kms^{-1}$ is the velocity dispersion, and $\hat{\phi} = v^2/{v_{esc}}^2$ is the dimensionless gravitational potential.

In the WIMP mass range 15 GeV-100 GeV this yields total capture rates of the order of $10^{17} sec^{-1}$ to $10^{18} sec^{-1}$. According to the equation above, this yields $\dot{Q}_E \sim 10^8 W - 10^{10} W$ for a uniform density distribution.

In the case of clumped DM with core densities 10^9 times the galactic halo density, global power production due to the passage of the earth through a DM clump is $\sim 10^{17} W - 10^{19} W$. It is to be noted that this heat generated in the core of the earth is huge and arises due to the highly clumped CDM [4].

If the dark matter is composed of neutralinos, the effect of geological heating may not be in the saturation regime [16] and this may diminish the heat production. The effect also depends on the unknown density inside the dark matter clump. The estimates show that in case of the neutralino, it can reach the right order of magnitude for extreme values of parameters. One should note however, that not only are the parameters of neutralino interactions not well known, but even the nature of the dark matter particles (neutralino or something else?) is not yet established. However, the bottom line is that our estimates should be relevant for non-standard neutralino parameters and/or other dark matter particles.

The geothermodynamic theory states that continuous heat absorption by the the lowermost layer of the mantle, the so called D" layer would result from a temporary increase in heat transfer from the core [17]. This process would continue until, due to its decreasing density, this layer becomes unstable, eventually breaking up into rising plumes. This is the only physical possibility as plume production is the most efficient way of heat transfer in earth. The lower mantle origin for plumes concept is strengthened by several recent observations. Firstly, high levels of primordial He-3 reported for Siberian flood basalts [18] support this view. Secondly, high levels of Osmium-187 from the decay of the Rhenium-187, found in high concentrations in the earth's core, observed in Siberian flood basalts [19], suggest that some of these rocks may even come from the outer core.

Due to its lower density, a typical plume created in this manner would well upwards. In this process, decompression of the plume on account of its ascent in a pressure gradient will lead to partial melting of the plume head, thereby producing copious amounts of basaltic magma [20]. Mantle velocities being ~ 1 m/year , such a plume would take ~ 5 million years to reach the crust. It would then melt its way through the continental crust, thereby producing viscous acidic (silicic) magma [21].

The ultimate arrival of such a plume head at the surface could be cataclysmic. Initial explosive silicic volcanism would be followed by periods of large-scale basalt volcanism that ultimately lead to the formation of massive flood basalt provinces such as the Siberian Traps, the Deccan Traps in India and the Brazilian Paraná basalts. Extensive atmospheric pollution would follow; the Deccan Trap flood basalt volcanic episode (~ 65 million years ago) ejected huge amounts of basalt, tonnes of H_2SO_4, HCl, and fine dust [21]. Climatic models predict that this is capable of triggering a chain of events ultimately leading to the depletion of the ozone layer, global temperature changes, acid rain and a decrease in surface ocean alkalinity.

Thus, Deccan volcanism has been proposed as a possible cause for the K/T (Cretaceous/Tertiary) mass extinction that extinguished the dinosaurs [20,22], while the Siberian basalts have been put forth as a possible culprit for the P/T (Permian/Triassic) mass extinction [20]. In fact, there exists a striking concordance between the ages of several major flood basalt provinces and the dates of the major palaeontological mass extinctions [17]. Hence it has been proposed by us [4] that all major periodic mass extinctions have been caused by gigantic volcanism which in turn were caused by the heat coming from dark matter annihilations at the centre of earth. So the actual culprit, for all major extinctions including that of dinosaurs, was the invisible dark matter [4,5].

Collar set forth the hypothesis that the passage of the clump leads to direct extinctions by causing cancers in organisms [14]. If this is correct, then this extinction should precede that due to volcanism by approximately 5 million years. Hence each major extinction should, at higher resolution, be a binary extinction: the first extinction due to the direct passage of the clump (causing cancers in various organisms), ie. the carcinogenic dark matter scenario, and the second extinction due to massive volcanism, ie. the volcanogenic dark matter scenario above. What is the empirical situation regarding this unique prediction of the dark matter extinction scenario ?

The Permo-Triassic extinction is the most severe ever recorded in the history of life on earth. It has been estimated that 88 - 96 % of all species disappeared in the final stages of the Permian. However, Stanley and Yang [23] discovered that this biotic crisis in fact consisted of two distinct extinction events. The first and less severe of the two was the Guadalupian crisis at the end of the penultimate stage of the Permian, followed after an interval of approximately 5 million years by the mammoth end-Tartarian event at the P/T boundary. Traditionally, the Signor-Lipps effect has been used to explain the high rates of extinction during the last two stages of the Permo-Triassic extinction. It was generally believed that the actual extinction occurred at the Permo-Triassic boundary during the end of the Tartarian stage, with the high Guadalupian metrics being due to the 'backward smearing' of the single grand extinction event. However, Stanley and Yang found that the high rates of extinction of the Guadalupian stage were not artifacts of the Signor-Lipps effect, but represent actual extinction. They conclude that the Permo-Triassic extinction consisted of two separate extinction events: the Guadalupian event when 71 % of marine species died out, and the Tartarian, with an 80 % disappearance of marine species still the largest mass extinction in paleontological history. The occurrence of two mass extinctions within 5 my of one another would be possible only if the causative mechanism of the first one had ceased to operate to allow for the observed recovery.

The Siberian flood basalt volcanic episode occurs during the end of the Tartarian and is a possible culprit for the Tartarian extinction. This volcanism commenced less than 600,000 years before the P/T boundary much after the Guadalupian extinction. Hence the Siberian Traps could not have been the cause of the Guadalupian extinction. In addition it is likely for the Late Devonian extinction to also consist of two separate extinction episodes; the Frasnian event followed after an interval by the terminal Fammenian extinction [23]. The occurrence of double extinctions is explained within the volcanogenic dark matter framework as explained above. In fact this is a unique and unambiguous prediction of this model.

Just as in the case of the earth, dark matter capture and annihilation in other planets and their satellites would lead to significant heat generation in these bodies for a uniform dark matter halo. This thermal output becomes enormous when clumped dark matter passes through the solar system. There are several evidences of clumpiness of dark matter in galactic halos [24]. This heat should be treated as a new source of heat in the planetary systems, at par with primordial accretional heat and radioactive heating. In may lie in the background or in special circumstances manifest itself more forcefully and directly. As such this new source of heat in the solar system may lead to unique imprints. Such new signatures of the dark matter are found in the generation of the recent completely unexpected discovery of the magnetic field of Ganymede along with the enigmatic Mercurian magnetic field. Standard conventional sources of heat are unable to give a reasonable description of these enigmatic magnetic fields. Careful calculations within the dark matter annihilation scenario enumerated here, explain them in a natural manner.

The volcanic hypothesis, despite providing a viable explanation for several features reported for mass extinctions, has always lacked a compelling reason for otherwise supposedly haphazard eruptions to occur in a periodic fashion. When one takes into account that the earth has been cooling ever since its formation (which implies a consequent decrease in volcanic activity), this objection becomes a serious weakness. It is hoped that a viable reason for large volcanic eruptions to occur in a periodic manner has been presented here with the introduction of the volcanogenic dark matter scenario. This should strengthen the volcanic hypothesis of mass extinctions and in addition explain the enigmatic magnetic fields of Ganymede and Mercury.

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